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DROUTH PERIODS AND CLIMATIC CYCLES

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The results obtained by Douglass (2, 1909, 1914) in relating the annual rings of trees to rainfall and to the sun-spot cycle first suggested the possibility of using the latter for forecasting rainfall from year to year. Practically all the groups of trees studied gave a clear record of growth cycles corresponding closely to the period of the sun-spot cycle. They confirmed the hypothesis that the years of sun-spot maxima were generally marked by deficient rainfall, and those of sun-spot minima by rainfall above the normal. A preliminary examination of the rainfall records for the States west of the Mississippi River showed that the two major drouth periods of 1893–95 and 1870–73 coincided with sun-spot maxima. It also became evident that excessive precipitation had occurred frequently, if not regularly, at the sun-spot minima. These facts suggested the probability of an excess of rainfall following the exceptional sun-spot minimum of 1913, and of a marked drouth period centering on the sun-spot maximum of 1917. The excess did not occur until 1914, and became general only in 1915, but its intensity was the greatest recorded for the region as a rule. This partial confirmation of the working hypothesis seemed to warrant a definite forecast of drouth at the 1917 maximum, a drought made more critical by the remarkable excess of 1915. The ecological studies throughout the West from 1916 to 1919 were based upon this assumption, as the following extracts indicate:

"The most attractive and promising feature of the summer's work has been the tracing and checking of the course of the present climatic cycle. The second recorded absolute minimum[1] of no sun-spots occurred in 1913, and served as the focus of a period of exceptional rainfall in the West. The drouth of the present summer (1916) in the Western and Mountain States suggests the beginning of the dry phase of the cycle. Its effect upon the carrying capacity of the ranges and upon the production of dry farms has been critical. Whether it be followed by the full period of several dry years or not, it has furnished further confirmation of the fact that all grazing and dry-farming must be based upon the recurrence of dry periods; in both, a scientific system of expansion and contraction must be devised to prevent disaster during dry years. If the next two or three years prove to be dry in harmony with the maximum of the sun-spot cycle, the possibility of anticipating dry seasons will be greatly enhanced. In the field of forestation much evidence has been obtained to show that planting is successful only during wet phases and that natural reproduction occurs practically only during such phases." (**1**, 1917.)

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[1] Wolfer's results, not available until August, 1920, give 1.4 as the year number.

"The investigation of climatic cycles has been continued from both the biological and astronomical approach. The former gains interest from the fact that the years 1916, 1917 and 1918 have in general been years of drouth in the West and especially the Southwest. This was suggested as a probability upon the approach of the sun-spot maximum in 1916. The maximum was passed in 1917, and attention is now centered upon the expected increase of rainfall generally as the sun-spot minimum is approached during the next four or five years. It is proposed to follow the biological effects as seen in growth, reproduction and abundance as closely as possible and to correlate these with the climatic phases. Striking evidences of these effects have been obtained during the drouth of the past two years. By far the most important problem, however, is the relation of the sun-spot cycle to the climatic and growth cycles. There appears to be little question of the usual coincidence of these three cycles, but the existence of a causal relation is still in doubt. In the endeavor to make use of the sun-spot cycle to anticipate climatic changes, this matter is of paramount importance." (**1**, 1918.)

The nature and consequences of the recent drouth are clearly exhibited by Graves (**1**, 1919, p. 14), who says that the season of 1918 marked the termination of a prolonged drouth throughout the Southwest; the season of 1919 was here unusually favorable, while to the north a severe drouth, which probably reached its greatest intensity in Montana, northern Wyoming, eastern Utah and Idaho prevailed to such an extent that the Department of Agriculture considered it necessary to assist the stockmen in these regions.

The principle of the excess-deficit balance was exemplified by the exceptional rainfall of 1919 in the Southwest (**1**, 1920, p. 266). Pearson (**6**) has shown that the coincidence of excessive rainfall with an extraordinary seed crop produced a remarkable development of yellow pine seedlings throughout the pine forests of New Mexico and Arizona. This enormous crop ranged from 10,000 to 400,000 seedlings per acre, and a survival of a fraction of one percent per acre will suffice to completely regenerate the forests concerned. Such a crop of seedlings can be expected once each double sun-spot cycle, the stimulus exerted by drouth resulting in greater seed production, and the subsequent high precipitation producing ideal conditions for germination.

A preliminary scrutiny of the rainfall records of the West revealed the basic relation of periods of severe drouth to the maximum of the sun-spot cycle (**1**, 1920, p. 251). The relation of periods of excessive rainfall to the minimum was less evident, or at least was much obscured by the effect of the excess-deficit balance. It was found that the drouth periods varied much in intensity, and that certain sun-spot maxima, such as those of 1883 and 1907, were not clearly represented by two or more years of drouth. As a consequence, it proved desirable to make a comprehensive analysis of the rainfall of all stations in the Western States with reference to this point. The States concerned extend from North Dakota to Texas and westward to the Pacific Coast. In addition, Minnesota, Iowa, Missouri, Wisconsin, Illinois and Indiana were taken into account as transition States in which the effect of severe drouth would be expected. After much consideration, it was decided that the use of plus or minus departures from the annual rainfall gave the simplest and best expression of the degree of drouth for each particular State. Accordingly, the rainfall records were examined for the twenty-three States concerned, involving somewhat more than 1,300 stations. As only periods of sun-spot maxima were taken into account, the departures from the normal were determined for the five years centering on the maximum. For example, a sun-spot maximum fell in 1917, and the period dealt with comprised the five years from 1915 to 1919, inclusive.

The resulting data are shown in the accompanying table, in which the States are grouped in regions that lie more or less at right angles to the movement of cyclonic areas. The table comprises 7 five-year periods, namely, 1915–1919, 1905–1909, 1892–1896, 1881–1885, 1869–1873, 1858–1862 and 1835–1839, and one six-year period, 1846–1851. The years on which the sun-spot maximum falls are 1917, 1907,[2] 1893, 1883, 1870, 1860, 1848 and 1837, and the corresponding cycles[3] are 11, 12, 10, 13, 10, 12 and 11 years long (7, 1920). The year of the maximum occupies the middle of each five-year period, with the exception of 1892–1896 and 1869–1873. Since the beginning of observations in 1750 the yearly number of sun-spots at the maximum has varied from 46 to 154, though the number has fallen below 80 for but five of the sixteen maxima. For the eight maxima considered here, the number of spots falls below 80 only in 1907 and 1883, when the numbers were 62 and 64, respectively. In other words, six of the maxima lie above 77—*i.e.,* half the number of spots for the highest maximum, 154.

For the period of 1915–1919 there was serious or critical drouth in every one of the 23 States concerned. The total number of minus departures from the normal rainfall was 1,166 stations in contrast to 183 plus departures. Moreover, either the year 1916 or 1918 was a year of drouth or great dryness in all the States; 1916 was dry in 11 States, 1918 in 15, and 1919 in 13. Seven States had three years of drouth in succession, 10 others had three years of drouth or dryness during the five-year period, while four had four years of drouth or dryness. In the Dakota-Texas series the drouth period comprised 1916, 1917 and 1918, while in the Minnesota-Indiana group 1916 was dry and 1917–1918 years of drouth. For the Montana-New Mexico

[2] The year 1905 was one of maximum also.

[3] Taken from Wolfer's smoothed means, which show the epoch more accurately.

Table I. Numbers of stations which show plus and minus departures from the normal rainfall by states and years.

The figures in the first line for each state represent plus departures, in the second line minus departures. Bold-face numbers indicate years of drouth, and italic, dry years.

Sunspots	47	55	**104**	81	64	*63*	54	*62*	48	45	73	**85**	78	64	42	54	60	*64*	63	52	74	**139**	111	102	66	55	94	**96**	77	59	61	98	**124**	96	66	64	57	121	**138**	103	86
Year.	'15	'16	'17	'18	'19	'05	'06	'07	'08	'09	'92	'93	'94	'95	'96	'81	'82	'83	'84	'85	'69	'70	'71	'72	'73	'58	'59	'60	'61	'62	'46	'47	'48	'49	'50	'51	'35	'36	'37	38	'39
N. D.	20	26	0	14	16	31	35	3	22	10	10	4	6	7	29	2	4	2	3	3		0	0	1	0																
	16	10	**52**	**34**	**33**	11	13	**40**	*17*	**16**	**12**	**21**	**21**	**21**	2	**3**	2	**4**	3	3		1	1	1	**2**																
S. D.	27	17	7	26	21	33	39	7	37	24	18	4	4	5	22	1	2	5	1	3	0	1	1	0	1																
	2	**19**	**37**	9	12	4	2	**31**	3	12	3	**23**	**23**	**25**	6	2	**3**	1	**4**	2	**2**	1	1	**2**	1																
Neb.	78	5	12	27	59	53	43	10	45	62	17	0	0	5	45	10	2	10	6	5		0	1	1	0											1					
	0	**75**	**70**	**57**	27	4	13	**43**	16	24	*17*	**40**	**42**	**49**	15	1	**6**	2	**8**	**9**		1	0	1	**2**											0					
Kan.	103	29	7	54	28	41	24	20	42	59	19	1	3	18	23	6	1	9	10	12	2	3	3	3	2	2	2	0	1	0	0	0	1	2	0	1		0	1	0	0
	0	**74**	**84**	40	**55**	8	**25**	**33**	11	19	*18*	**37**	**39**	**23**	**24**	6	**10**	5	5	3	2	**5**	**5**	**6**	**6**	0	0	2	2	3	2	2	1	0	2	1		1	0	1	1
Okl.	43	14	1	35	21	36	30	18	40	7	7	1	0	9	1	0	0	1	2	0																					
	0	**30**	**46**	12	*19*	9	15	**27**	5	**34**	1	**7**	**14**	6	**13**	0	0	0	0	1																					
Tex.	61	13	1	44	111	108	63	70	76	12	25	5	28	56	36	11	20	7	11	11	3	3	0	2	9	2	1	2	0	0					3	3					
	41	**91**	**110**	**67**	3	8	47	48	52	**114**	**31**	**57**	**41**	14	**42**	**19**	4	4	1	4	0	1	**10**	**11**	9	5	10	7	1	1					1	1					
Total.	332	104	28	200	256	302	234	128	262	174	95	15	41	100	157	30	29	34	33	34	5	7	5	7	12	4	3	2	1	0	0	0	1	2	3	5		0	1	0	0
	59	**299**	**399**	**219**	149	44	115	**222**	104	**219**	*82*	**185**	**180**	**138**	102	**31**	*25*	16	21	22	4	**9**	**17**	**21**	**29**	**5**	**10**	**9**	**3**	**4**	2	2	1	0	3	2		1	0	1	1
Minn.	40	39	13	22	33	55	46	8	41	28	21	8	1	5	51	5	4	2	4	0	2	2	3	3	4	0	1	1	1	1	0	0	0	1	0	0			0	0	0
	12	18	**51**	**37**	22	4	9	**48**	17	13	11	**37**	**49**	**51**	6	1	3	**5**	3	**9**	1	1	1	2	3	2	1	0	0	0	1	1	1	0	1	1			1	1	1
Iowa.	81	18	7	39	71	91	45	54	75	110	33	2	0	5	65	31	22	23	25	21	9	0	2	6	3	6	2	0	4	5	0	0	1	2	2	3					
	2	**66**	**79**	*39*	17	17	**61**	*49*	30	4	10	**49**	**56**	**66**	10	0	9	6	5	5	0	**7**	**4**	5	**7**	0	3	4	1	0	1	1	0	0	0	0					
Mo.	59	34	4	18	34	53	24	27	41	57	32	20	7	29	32	20	20	18	17	13	5	0	0	1	2	3	2	0	2	2	1	1	1	2	2	2					
	4	*33*	**63**	**49**	*30*	9	**36**	**29**	17	11	6	**29**	**50**	**31**	**34**	13	11	9	10	**15**	2	**5**	**7**	**4**	**6**	0	1	4	2	2	0	1	1	0	0	0					
Wis.	33	39	12	15	37	44	40	26	13	30	30	13	7	1	26	6	4	5	4	5	2	1	1	0	2																
	12	16	**43**	**30**	14	6	8	*22*	**38**	21	3	**22**	**30**	**39**	16	0	2	1	2	1	*2*	**3**	**3**	**5**	**3**																
I.	54	37	9	34	36	26	35	54	19	73	24	12	0	4	30	13	17	18	17	14	6	0	3	3	2	7	2	0	2	4											
	8	23	**52**	*29*	28	**38**	*31*	8	**45**	1	5	**21**	**40**	**41**	*26*	4	1	1	3	7	1	**8**	**5**	**7**	**9**	1	5	3	3	0											
Ind.	33	28	15	25	23	42	25	46	5	50	13	19	2	1	23	7	9	14	8	7	5	1	1	1	6	2	2	0	0	3											
	14	20	**33**	*22*	*21*	7	**27**	6	**49**	4	**16**	11	**30**	**32**	15	2	1	1	**11**	**19**	2	**4**	**6**	**6**	1	0	0	2	3	0											
Total.	300	185	60	153	234	311	215	215	194	348	153	74	17	45	227	82	76	80	75	60	29	4	10	14	19	18	9	1	9	14	1	1	2	5	4	5		0	0	0	
	52	*176*	**321**	**206**	132	81	172	152	**196**	54	51	**169**	**255**	**260**	107	20	27	23	34	*56*	8	**28**	**26**	**29**	**29**	3	**10**	**13**	*9*	2	2	3	2	0	1	1		1	1	1	

Mon.	28	30	12	17	1	9	37	34	43	20	5	1	7	6	18	5	4	1	5	3	1	1	1	1	0																
	6	7	**30**	**33**	**51**	**32**	20	20	14	2	**6**	**7**	*6*	**13**	8	3	**6**	**5**	3	**6**	1	**2**	**2**	**2**	**3**																
Wyo.	20	5	5	16	1	22	30	12	14	20	5	2	1	8	6	0	1	1	1	1	0	0	1	2	3																
	6	**23**	**18**	9	**32**	11	6	**24**	7	8	1	**7**	**7**	1	4	1	1	0	0	0	**3**	**3**	**2**	**1**	**1**																
Col.	43	28	11	53	31	49	57	28	33	71	24	11	21	48	17	2	2	2	4	5	2	1	1	3	1		1	0	0	0											
	16	**32**	**54**	13	*26*	16	9	**47**	**45**	10	**33**	**50**	**39**	17	**42**	1	**4**	**3**	1	1	1	**2**	**2**	1	*4*		0	1	1	1											
N. M.	32	25	0	36	85	39	42	36	9	23	1	9	3	15	10	4	1	1	5	2	6	5	3	5	2	3	3	0	2	1					0	1					
	14	*22*	**55**	*30*	9	2	14	23	**53**	**41**	**22**	**12**	**19**	*12*	**21**	1	**6**	**3**	1	**7**	2	3	**5**	3	**5**	3	2	**5**	0	0					4	0					
Total.	123	88	28	122	128	119	166	110	99	134	35	23	32	77	51	11	8	5	15	11	9	7	6	11	6	3	4	0	2	1					0	1					
	42	*84*	**157**	85	*118*	61	49	**114**	**119**	61	**62**	**76**	**71**	43	**75**	6	**17**	**11**	5	**14**	7	**10**	**11**	7	**13**	3	2	**6**	1	1					4	0					
Ida.	11	13	8	6	3	2	15	20	9	10	1	3	8	1	12	2	3	0	2	1																					
	13	*9*	**14**	**24**	**38**	**21**	8	6	**18**	5	**3**	**6**	4	**14**	2	1	1	**2**	1	2																					
Ut.	19	22	7	22	6	32	45	36	33	42	5	11	8	5	6	2	1	0	5	4			2	0	1																
	11	6	**34**	*18*	**32**	18	1	7	10	3	**11**	*6*	**11**	**18**	**16**	2	**4**	**5**	0	0			1	**3**	1																
Nev.	8	9	2	14	6	5	18	19	8	25	16	13	19	4	20	6	11	6	16	10																					
	18	*8*	**21**	7	**18**	**17**	3	1	**16**	4	*16*	**18**	*14*	**31**	13	**13**	6	**10**	2	8																					
Ariz.	35	43	16	24	52	43	25	32	33	23	7	8	8	11	17	9	8	9	14	0	1	1	0	2	2																
	10	5	**32**	*19*	2	0	14	13	9	**17**	**19**	**18**	**23**	**17**	11	6	5	4	1	**16**	**3**	**4**	**4**	2	**4**																
Total.	73	87	33	66	67	82	103	107	83	100	29	35	43	21	55	19	23	15	37	15	1	1	2	2	3																
	52	28	**101**	**68**	**90**	56	26	27	53	29	**49**	**48**	**51**	**80**	42	**22**	16	**21**	4	**26**	**3**	**4**	**5**	**5**	**5**																
Wash.	**20**	31	19	11	17	18	41	22	8	25	10	18	19	1	25	6	6	0	4	2		1	2	0	0	2	1	1	1	0											
	25	13	**32**	**41**	**40**	**32**	8	**29**	**43**	19	*8*	0	5	**19**	4	0	1	**6**	4	**8**		1	0	**1**	**2**	0	0	1	0	1					1	0					
Ore.	17	26	13	0	30	1	40	43	2	43	4	37	39	15	44	12	8	1	5	4		0	3	3	1	4	3	1	4	1					0	1					
	21	14	**32**	**49**	*24*	**58**	22	17	**57**	5	**43**	9	6	**30**	2	0	4	**9**	**10**	**11**	1	**3**	1	2	**4**	2	1	**4**	0	**3**											
Cal.	148	119	2	57	7	78	203	184	21	182	85	60	100	55	124	19	11	6	78	13	4	1	11	9	3	1	1	1	3	4					1	0					
	32	35	**124**	**96**	**140**	**130**	5	31	**204**	1	46	**84**	53	**104**	44	**65**	**75**	**82**	6	**76**	*5*	**13**	**15**	**22**	**35**	**3**	**3**	**3**	1	0					4	4					
Total.	185	176	34	68	54	97	284	249	31	250	99	105	158	71	191	37	25	7	87	19	4	2	16	12	4	7	5	3	8	5					1	1					
	78	62	**188**	**186**	**204**	**220**	35	77	**304**	25	*97*	*91*	66	**153**	50	**65**	**80**	**97**	20	**95**	*6*	**17**	*16*	**25**	**41**	5	4	**8**	1	4					5	4					
Grand Total.	1013	640	183	609	739	911	1002	809	669	1006	412	252	291	314	681	179	161	141	247	139	48	21	39	48	44	32	21	6	19	20	1	1	3	7	8	12		0	1	0	0
	283	**649**	**1166**	**764**	*693*	462	397	592	**776**	388	341	**569**	**623**	**674**	376	144	**165**	**168**	84	**213**	28	**68**	**75**	**87**	**118**	16	**26**	**36**	*14*	11	**4**	**5**	3	0	*8*	7		**2**	1	**2**	**2**

series 1917 was the only year of drouth, though 1916 and 1919 were dry. For the Great Basin and the Coast States all three years, 1917, 1918, 1919, were ones of great or exceptional drouth. For the West as a whole 1916, 1917 and 1918 constituted the drouth period, while 1919 was dry, being wet in the Middle West and showing drouth in the Far West. The year 1915 was wet throughout, and exceptionally so except in the Idaho-Arizona group. The significance of this is suggested later.

The period of 1905–1909 shows little evidence of drouth. The year 1907 was one of drouth in the Middle West, but of rather more than normal precipitation in the Far West. The next year was a wet one in the Middle West generally, but the three eastern States and the Far West showed drouth. There were 11 drouth or dry States in 1907 and 12 in 1908. The totals for plus and minus stations show that 1907 was wet on the whole, while 1908 was dry. The other three years were wet.

The period of 1892–1896 resembles that of 1915–1919 in the extent and intensity of drouth, although no one year showed drouth in all the States. However, drouth occurred in 19 States in 1893, in 17 States in 1894 and in 18 States in 1895. Thirteen States had three years of drouth in succession, and two others had four such years in succession, while three more had three drouth years in the five. In the Middle West 1893, 1894 and 1895 were the critical years, but in the Far West they were 1892, 1893 and 1895. The Pacific Coast was merely dry in the first two, and drouth came only in 1895, as it did also in the Great Basin, making a period of four years. For the region as a whole, the number of stations with minus departures was more than twice the number with plus departures. The effects of drouth were already felt in 1892, but 1896 was a wet year, as would be expected.

The period of 1881–1885 was much drier than the one centering about the maximum of 1906, but it can not be considered a drouth period in comparison with those of 1915–1919 and 1892–1896. For the Dakota-Texas series 1881 is barely to be accounted a drouth year, while 1882 is merely dry. The Minnesota-Indiana group was wet throughout, except for the dry year of 1885. By contrast, the three groups of the Far West exhibit at least three years of drouth, and the year of the maximum, 1883, shows drouth in all. Three consecutive years occur only in the Coast group, in which four of the five years are critical. For the West as a whole, 1882, 1883 and 1885 were years of some drouth, while 1881 was rather wet and 1885 quite so.

For the period of 1869–1873 the number of stations for each State is often too small to furnish conclusive evidence. The regional totals, however, clearly indicate widespread drouth. Thus the Middle West shows four successive years of drouth, 1870–1873, the Great Basin three years, and the Pacific Coast five years. This is reflected in the totals for the West, in which 1870, 1871, 1872 and 1873 are years of general drouth, and 1869 a wet year.

The earlier periods are represented by so few stations that the totals alone are of value. These indicate that 1859, 1860 and 1861 constituted a drouth period, while 1858 and 1862 were wet years. A similar tendency to drouth is shown in the periods 1846–1851 and 1835–1839, but the number of stations is too small to be anything more than suggestive.

An examination of the totals for the six important periods shows three consecutive years of drouth in the period of 1915–1919, three in 1892–1896, four in 1869–1873 and three in 1858–1862. Of the others, 1881–1885 contained three years of moderate drouth intensity and 1905–1909 a single year. In seeking a possible relation between this and the sun-spot numbers, it was found that the four periods of critical drouth centered on maxima of 85 or more spots, while the maxima of the other two periods were 64 and 62, respectively. As indicated earlier, the greatest number of spots recorded for any maximum is 154 for the maximum of 1778. Hence the maxima which correspond to periods of intense drouth are characterized by spot numbers in excess of half of the greatest number known for any year's sun-spot maximum, while those for the periods of 1905–1909 and 1881–1885 are below the half of this number. The crest of the curve for these two periods is also very flat. In consequence, it may be said that a critical drouth period has occurred in the West since 1858, and perhaps since 1835, at each sun-spot maximum for which the spot number was greater than half the number known for the year maximum. This does not mean that drouth years have not occurred at other times, but a preliminary examination of the records for the years centering about the sun-spot minima shows no general and critical drouth throughout the West at such times. The periods of the minimum are now being analyzed with reference to this point, as also to the relation of the sun-spot minimum to increased or excessive rainfall. In addition, all station records of twenty years or longer are being charted as columnar graphs for the purpose of throwing light on the 2–3-year cycle and on the question of its relationship to the sun-spot cycle. In both cases it is hoped that a clue may be found to the operation of the excess-deficit balance, and its effect in modifying conditions at the sun-spot maximum or minimum. This relation is suggested by the fact that each drouth period in the table is either ushered in or closed by a year of excessive rainfall.

The importance to agriculture, grazing and forestry of being able to anticipate periods of serious drouth has been discussed in some detail in "Plant Indicators" (1, 1920, pp. 254, 334, 359). The periods of critical drouth have had disastrous effects upon the settlement and development of the West, and similar consequences must be expected until the recurrence of drouth is accepted as inevitable and proper precautions taken against it. The extent to which the sun-spot cycle can be utilized in predicting periods of drouth or wetness can be determined only by actual trial. The success attending the first attempt to do this may have been purely accidental.

However, the results of Douglass (**2**, 1909, 1914, 1920), Huntington (**4**) and Kapteyn (**5**) on the rings of trees, and the grand totals of the accompanying table seem to indicate clearly the basic importance of the sun-spot cycle for long-range forecasting.

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